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Specification and Guidelines for **Self-Compacting Concrete**

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FOREWORD

EFNARC is the European federation dedicated to specialist construction chemicals and concrete systems. It was founded in March 1989 as the European federation of national trade associations representing producers and applicators of specialist building products. Membership has since widened and now includes many of the major European companies who have no national trade association to represent their interests either at national or European level. **EFNARC** members are active throughout all the countries of Europe.

EFNARC main activities at European level and at CEN Technical committees are in flooring, the protection and repair of concrete, in soft ground tunnelling, in sprayed concrete, and now in self-compacting concrete. It provides a common voice for the industry to make known its position and view to the European Commission departments dealing with the CPD, CEN Technical Committees and other Groups dealing with European harmonisation of Specifications, Standards, Certification and CE marking relevant to our industry.

In each product area it operates through specialist Technical Committees that have been responsible for producing Specifications and Guidelines which have become recognised as essential reference documents by specifiers, contractors and material suppliers throughout Europe and beyond.

The utilisation of Self-compacting Concrete (SCC) is growing rapidly. The concrete community of various European countries intensely researches its application and implements experiences. This Specification and Guideline utilises EFNARC's broad practical experience with SCC to provide a framework for design and use of high quality SCC. It is based on the latest research findings as well as an abundance of field experience from EFNARC's members all over Europe.

However EFNARC recognises that this is a technology which is still evolving and further advances may require this Specification's requirements to be modified or extended. The responsible Technical Committee will continue to monitor progress in this field and it is our intention to update the document at regular intervals. Feedback from those using this document is therefore invited and will be taken into account at the next revision.

All comments on this specification and its requirements should be submitted to:

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1 INTRODUCTION

Self-compacting concrete (SCC) has been described as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labour, it has proved beneficial economically because of a number of factors, including:

- faster construction
- reduction in site manpower
- better surface finishes
- easier placing
- improved durability
- greater freedom in design
- thinner concrete sections
- reduced noise levels, absence of vibration
- safer working environment

Originally developed in Japan, SCC technology was made possible by the much earlier development of superplasticisers for concrete. SCC has now been taken up with enthusiasm across Europe, for both site and precast concrete work. Practical application has been accompanied by much research into the physical and mechanical characteristics of SCC and the wide range of knowledge generated has been sifted and combined in this guideline document.

2 SCOPE

The EFNARC Specification defines specific requirements for the SCC material, its composition and its application. The Annexes also include a wealth of useful advice to designers, concrete manufacturers, contractors, specifying authorities and testing organisations.

3 REFERENCED STANDARDS

EN 197-1	Cement ; Composition, specifications and conformity criteria
EN 206-1	Concrete – Specification, performance, production, and conformity
EN 450	Fly ash for concrete – Definitions, requirements and quality control
EN 934-2	Admixtures for concrete – Definitions and requirements
EN 1008	Mixing water for concrete
EN 12350-1	Testing fresh concrete: Part 1: Sampling
EN 12350-2	Testing fresh concrete: Part 2: Slump test
EN 12620	Aggregates for concrete
EN 12878	Pigments for colouring of building materials based on cement ...
EN 13263	Silica fume for concrete – Definitions, requirements and conformity control
EN ISO 9001	Quality management systems – Requirements

Note : Some of these EN standards may still be in preparation; the latest version should be referred to.

4 DEFINITIONS

For the purposes of this specification, the following definitions apply:

4.1 Addition

Finely-divided inorganic material used in concrete in order to improve certain properties or to achieve special properties. This specification refers to two types of inorganic additions:

- nearly inert additions (Type I);
- pozzolanic or latent hydraulic additions (Type II)

4.2 Admixture

Material added during the mixing process of concrete in small quantities related to the mass of cement to modify the properties of fresh or hardened concrete.

4.3 Binder

The combined cement and hydraulic addition in a self-compacting concrete

4.4 Confined flowability see: 4.9 Passing ability

4.5 Filling ability (unconfined flowability)

The ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight

4.6 Fines see: 4.10 Powder

4.7 Mortar

The fraction of the concrete comprising Paste plus those aggregates less than 4 mm.

4.8 Paste

The fraction of the concrete comprising Powder plus water and air.

4.9 Passing ability (confined flowability)

The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.

4.10 Powder (Fines)

Material of particle size smaller than 0,125 mm. It will also include this size fraction of the sand.

4.11 Self-compacting concrete (SCC)

Concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity.

4.12 Segregation resistance (stability)

The ability of SCC to remain homogeneous in composition during transport and placing.

4.13 Stability see: 4.12 Segregation resistance

4.14 Unconfined flowability see: 4.5 Filling ability

4.15 Workability

A measure of the ease by which fresh concrete can be placed and compacted: it is a complex combination of aspects of fluidity, cohesiveness, transportability, compactability and stickiness.

5 REQUIREMENTS FOR CONSTITUENT MATERIALS

5.1 General

The constituent materials, used for the production of Self-Compacting Concrete (SCC) shall generally comply with the requirements of EN 206.

The materials shall be suitable for the intended use in concrete and not contain harmful ingredients in such quantities that may be detrimental to the quality or the durability of the concrete, or cause corrosion of the reinforcement.

5.2 Cement

General suitability is established for cement conforming to EN 197-1.

5.3 Aggregates

Aggregates shall conform to EN 12620. The maximum size of the aggregates depends on the particular application and is usually limited to 20 mm.

Particles smaller than 0,125 mm contribute to the powder content.

The moisture content should be closely monitored and must be taken into account in order to produce SCC of constant quality (see 8).

5.4 Mixing Water

Suitability is established for mixing water and for recycled water from concrete production conforming to EN 1008.

5.5 Admixtures

Admixtures used shall comply with EN 934-2: 2000 (including Annex A), where appropriate.

Superplasticizers are an essential component of SCC to provide the necessary workability. Other types may be incorporated as necessary, such as Viscosity Modifying Agents (VMA) for stability, air entraining admixtures (AEA) to improve freeze-thaw resistance, retarders for control of setting, etc.

VMA admixtures are not specifically covered in EN 934, but should conform to the general requirements in Table 1 of that standard. In addition evidence of performance should be provided by the supplier.

5.6 Additions (including mineral fillers and pigments)

General suitability as Type I (semi-inert) addition is established for:

- filler aggregate conforming to EN 12620
- pigments conforming to EN 12878

General suitability as Type II (pozzolanic or latent hydraulic) addition is established for:

- fly ash conforming to EN 450
- silica fume conforming to prEN 13263
- ground granulated blastfurnace slag conforming to BS 6699

Due to the special rheological requirements of SCC, both inert and reactive additions are commonly used to improve and maintain the workability, as well as to regulate the cement content and so reduce the heat of hydration. Type II additions can significantly improve the long term performance of the concrete.

Typical additions are:

Stone powder. Finely crushed limestone, dolomite or granite may be used to increase the amount of powder: the fraction less than 0.125 mm will be of most benefit. Note: dolomite may present a durability risk due to alkali-carbonate reaction.

Fly Ash. Fly ash is a fine inorganic material with pozzolanic properties, which can be added to SCC to improve its properties. However the dimensional stability may be affected and should be checked.

Silica Fume. Silica fume gives very good improvement of the rheological as well as the mechanical and chemical properties. Improves also the durability of the concrete.

Ground (Granulated) Blast Furnace Slag. GGBS is a fine granular mostly latent hydraulic binding material, which can also be added to SCC to improve the rheological properties.

Ground Glass Filler. This filler is usually obtained by finely grinding recycled glass. The particle size should be less than 0,1 mm and the specific surface area should be $> 2500 \text{ cm}^2/\text{g}$. Larger particle sizes may cause Alkali-Silica reaction.

Pigments. The suitability of pigments used in SCC is established in EN 12878.

5.7 Fibres

Fibres used in SCC shall comply with EN XXXX (European standard – in preparation). Commonly used types of fibres are steel or polymer.

Fibres may be used to enhance the properties of SCC in the same way as for normal concrete. Steel fibres are used normally to enhance the mechanical characteristics of the concrete such as flexural strength and toughness. Polymer fibres may be used to reduce segregation and plastic shrinkage, or to increase the fire resistance. Ease of mixing and the placing processes proposed, shall be demonstrated by site trials to the approval of the engineer.

6 REQUIREMENTS FOR SELF-COMPACTING CONCRETE

6.1 Application area

SCC may be used in pre-cast applications or for concrete placed on site. It can be manufactured in a site batching plant or in a ready mix concrete plant and delivered to site by truck. It can then be placed either by pumping or pouring into horizontal or vertical structures. In designing the mix, the size and the form of the structure, the dimension and density of reinforcement and cover should be taken in consideration. These aspects will all influence the specific requirements for the SCC.

Due to the flowing characteristics of SCC it may be difficult to cast to a fall unless contained in a form.

SCC has made it possible to cast concrete structures of a quality that was not possible with the existing concrete technology.

6.2 Requirements

SCC can be designed to fulfil the requirements of EN 206 regarding density, strength development, final strength and durability.

Due to the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC. Current knowledge of these aspects is limited and this is an area requiring further research. Special care should also be taken to begin curing the concrete as early as possible.

The workability of SCC is higher than the highest class of consistence described within EN 206 and can be characterised by the following properties:

- Filling ability
- Passing ability
- Segregation resistance

A concrete mix can only be classified as Self-compacting Concrete if the requirements for all three characteristics are fulfilled.

6.3 Test methods

Many different test methods have been developed in attempts to characterise the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly no single method has been found which characterises all the relevant workability aspects so each mix design should be tested by more than one test method for the different workability parameters.

Alternative test methods for the different parameters are listed in Tables 1 and 2. The test methods are described in detail in Annex D.

Table 1: List of test methods for workability properties of SCC

	Method	Property
1	Slump-flow by Abrams cone	Filling ability
2	T _{50cm} slumpflow	Filling ability
3	J-ring	Passing ability
4	V-funnel	Filling ability
5	V-funnel at T _{5minutes}	Segregation resistance
6	L-box	Passing ability
7	U-box	Passing ability
8	Fill-box	Passing ability
9	GTM screen stability test	Segregation resistance
10	Orimet	Filling ability

For the initial mix design of SCC all three workability parameters need to be assessed to ensure that all aspects are fulfilled. A full-scale test should be used to verify the self-compacting characteristics of the chosen design for a particular application.

For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are Slump-flow and V-funnel or Slump-flow and J-ring. With consistent raw material quality, a single test method operated by a trained and experienced technician may be sufficient.

Table 2: Workability properties of SCC and alternative test methods

Property	Test methods		
	Lab (mix design)	Field (QC)	Modification of test according to max. aggregate size
Filling ability	1 Slumpflow 2 T _{50cm} slumpflow 4 V-funnel 10 Orimet	1 Slumpflow 2 T _{50cm} slumpflow 4 V-funnel 10 Orimet	none max 20 mm
Passing ability	6 L-box 7 U-box 8 Fill-box	3 J-ring	Different openings in L-box, U-box and J-ring
Segregation resistance	9 GTM test 5 V-funnel at T _{5minutes}	9 GTM test 5 V-funnel at T _{5minutes}	None

6.4 Workability criteria for the fresh SCC

These requirements are to be fulfilled at the time of placing. Likely changes in workability during transport should be taken into account in production.

Typical acceptance criteria for Self-compacting Concrete with a maximum aggregate size up to 20 mm are shown in Table 3.

Table 3: Acceptance criteria for Self-compacting Concrete.

	Method	Unit	Typical range of values	
			Minimum	Maximum
1	slumpflow by Abrams cone	mm	650	800
2	T _{50cm} slumpflow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
5	Time increase, V-funnel at T _{5minutes}	sec	0	+3
6	L-box	(h ₂ /h ₁)	0,8	1,0
7	U-box	(h ₂ -h ₁) mm	0	30
8	Fill-box	%	90	100
9	GTM Screen stability test	%	0	15
10	Orimet	sec	0	5

These typical requirements shown against each test method are based on current knowledge and practice. However future developments may lead to different requirements being adopted. Values outside these ranges may be acceptable if the producer can demonstrate satisfactory performance in the specific conditions, eg, large spaces between reinforcement, layer thickness less than 500 mm, short distance of flow from point of discharge, very few obstructions to pass in the formwork, very simple design of formwork, etc.

Special care should always be taken to ensure no segregation of the mix is likely as, at present, there is not a simple and reliable test that gives information about segregation resistance of SCC in all practical situations. Further important comments on the suitability of the test methods are provided in Annex D.

7 MIX COMPOSITION

7.1 General

The mix composition shall satisfy all performance criteria for the concrete in both the fresh and hardened states. For the fresh concrete, the requirements are set out in 6. In the hardened state, the requirements of EN 206 shall be fulfilled.

7.2 Initial mix composition:

In designing the mix it is most useful to consider the relative proportions of the key components by *volume* rather than by mass.

Indicative typical ranges of proportions and quantities in order to obtain self-compactability are given below. Further modifications will be necessary to meet strength and other performance requirements.

- Water/powder ratio by volume of 0.80 to 1.10
- Total powder content - 160 to 240 litres (400-600 kg) per cubic meter.
- Coarse aggregate content normally 28 to 35 per cent by volume of the mix.
- Water:cement ratio is selected based on requirements in EN 206. Typically water content does not exceed 200 litre/m³.
- The sand content balances the volume of the other constituents

Generally, it is advisable to design conservatively to ensure that the concrete is capable of maintaining its specified fresh properties despite anticipated variations in raw material quality. Some variation in aggregate moisture content should also be expected and allowed for at mix design stage. Normally, viscosity-modifying admixtures are a useful tool for compensating for the fluctuations due to any variations of the sand grading and the moisture content of the aggregates.

7.3 Adjustment of the mix

Laboratory trials should be used to verify properties of the initial mix composition. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale at the concrete plant or at site.

In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate:

- using additional or different types of filler, (if available);
- modifying the proportions of the sand or the coarse aggregate;
- using a viscosity modifying agent, if not already included in the mix;
- adjusting the dosage of the superplasticizer and/or the viscosity modifying agent;
- using alternative types of superplasticizer (and/or VMA), more compatible with local materials;
- adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

8 PRODUCTION AND PLACING

8.1 General

The production of self-compacting concrete needs to be carried out in plants where the equipment, operation and materials are suitably controlled. Production should therefore be carried out at ISO 9000 accredited plants or plants with a quality systems that conforms to ISO 9000 or similar. It is recommended that production staff involved in the production of self-compacting concrete have been trained and also have experience in self-compacting concrete.

8.2 Production

8.2.1 Storage of constituent materials

If possible, aggregates should be covered to minimise the fluctuation of surface moisture content. It is also necessary to have good storage capacity for aggregates and additions (if used).

Storage of concrete admixtures can be done in the same way as for normal concrete. The supplier's recommendations should be followed.

8.2.2 Mixing

There is no requirement for any specific mixer type. Forced action mixers, including paddle mixers, free fall mixers, including truck mixers, and other types can all be used. The mixing time necessary should be determined by practical trials. Generally, mixing times need to be longer than for conventional mixes.

Time of addition of admixture is important, and procedures should be agreed with the supplier after plant trials. If the consistence has to be adjusted after initial mixing, then it should generally be done with the admixtures. If the requirements of EN 206 for the water/cement ratio can be maintained, then the water content can be varied to make the necessary modification.

8.3 Production Control

8.3.1 Aggregates

During production of SCC, tests of aggregate grading and moisture content should be carried out more frequently than usual, since SCC is more sensitive than normal concrete to variations.

8.3.2 Mixing process

At the start of a contract and in the absence of previous experience with the particular mix design, additional resources may be needed for supervision of all aspects of initial production of SCC.

Since the quality of freshly mixed concrete may fluctuate at the beginning of production, it is recommended that workability tests should be conducted by the producer on every load, until consistent and compliant results are obtained. Subsequently, every delivered batch should be visually checked before transportation to site, and routine testing carried out to the frequency specified in EN206.

More frequent adjustment of mix proportions, particularly water content, may need to be made, depending on the results from monitoring aggregate moisture content.

8.4 Delivery and transportation

Depending on the size of the concrete structure to be produced in SCC, production capacity, journey time and placing capability need to be balanced. Unexpected production stops can result in consistence variations that adversely affect the end result.

SCC should be designed so that workability is maintained to meet the requirements of the contract. Placing is faster, especially if a pump is used, but it is still essential to make sure that delivery and placing can be completed within the workability-retention (self-compactability) time of the concrete.

8.5 Placing

8.5.1 General

Before placing SCC, It should be confirmed that reinforcement and formwork are arranged as planned. The formwork must be in good condition but no special measures are necessary to prevent grout loss. Contractors may wish to consider possible advantages of pumping from the bottom of formwork. If concrete is placed by skip, attention should be paid to the closure of the gate.

For forms in excess of 3 m in depth, the full hydrostatic head should be taken into consideration. This may require modification of the formwork design and/or the SCC.

8.5.2 Placing distance

Though it is easier to place SCC than ordinary concrete, the following rules are advised to minimise the risk of segregation:

- limit the vertical free fall distance to 5 m
- limit the permissible distance of horizontal flow from point of discharge to 10 m.

Note: this advice is conservative, and it may be that in favourable circumstances a contractor can demonstrate that the suggested limits can be extended. See 6 for procedures.

8.5.3 Cold joints

Although SCC bonds well with previously placed concrete, the likelihood of damage resulting from a cold joint cannot be mitigated by vibration, as with normal concrete.

8.5.4 Surface finishing

Surfaces of SCC should be roughly levelled to the specified dimensions, and the finishing should then be applied at an appropriate time before the concrete stiffens. Difficulty may be encountered with the conventional process of final surface hardening of horizontal areas of concrete by repeated steel trowelling. Alternative procedures, or different tools may be required.

8.6 Curing

SCC tends to dry faster than conventional concrete because there is little or no bleed water at the surface. Initial curing should therefore be commenced as soon as practicable after placing in order to minimise the risk of shrinkage cracking.

9 QUALITY CONTROL

9.1 Production control

All SCC shall be subject to production control under the responsibility of the producer, and this shall be in accordance with the requirements of EN 206-1, clause 9.

9.2 Site acceptance

In the case of SCC it is particularly important that receiving control be standardised. Producer and purchaser should therefore agree a procedure for acceptance/compliance at the start of a contract. This should include a procedure for action to be taken in the event of non-compliance.

Beside the normal check of delivery ticket, a visual check of the concrete should be made. Site quality control should follow the recommendations of **6.3**.

The purchaser should ensure that all site acceptance testing is carried out by competent, trained personnel, in a suitable environment – this includes an area protected against the weather, suitably maintained and calibrated equipment, and level, stable ground for performing the test.

EFNARC Specification and Guidelines for Self-Compacting Concrete

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ANNEX A: GUIDANCE NOTES

A.1 SCOPE

The scope of the Guidance Notes section is to provide practical advice on aspects that may not be specified. National practices sometimes vary, often due to availability of cement additions, properties of aggregates or climatic conditions.

EFNARC's European network of construction professionals provides an abundance of experience covering useful aspects of designing, producing and placing self-compacting concrete.

A.2 REQUIREMENTS FOR CONSTITUENT MATERIALS

Cement

All types of cements conforming to EN 197 are suitable. Selection of the type of cement will depend on the overall requirements for the concrete, such as strength, durability, etc.

C₃A content higher than 10% may cause problems of poor workability retention.

The typical content of cement is 350-450 Kg/m³.

More than 500 Kg/m³ cement can be dangerous and increase the shrinkage.

Less than 350 Kg/m³ may only be suitable with the inclusion of other fine filler, such as fly ash, pozzolan, etc.

Aggregates

Sand

All normal concreting sands are suitable for SCC. Both crushed or rounded sands can be used. Siliceous or calcareous sands can be used.

The amount of fines less than 0,125 mm is to be considered as powder and is very important for the rheology of the SCC. A minimum amount of fines (arising from the binders and the sand) must be achieved to avoid segregation.

Coarse Aggregates

All types of aggregates are suitable. The normal maximum size is generally 16-20 mm; however particle sizes up to 40 mm or more have been used in SCC. Consistency of grading is of vital importance.

Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because of the interlocking of the angular particles, whilst rounded aggregates improve the flow because of lower internal friction.

Gap graded aggregates are frequently better than those continuously graded, which might experience greater internal friction and give reduced flow.

Admixtures

The most important admixtures are the Superplasticizers (high range water reducers), used with a water reduction greater than 20 %.

The use of a Viscosity Modifying Admixture (VMA) gives more possibilities of controlling segregation when the amount of powder is limited. This admixture helps to provide very good homogeneity and reduces the tendency to segregation.

Additions

Additions are commonly used in SCC due to the need for substantial contents of fine particles. All additions conforming to the EN standards are suitable.

Due to the special rheological requirements of SCC, both inert and reactive additions are commonly used to improve and maintain the workability, as well as to regulate the cement content and so reduce the heat of hydration. Type II additions can significantly improve the long-term performance of the concrete.

Fibres

Very fine synthetic fibres may prevent flow and generally the content should not exceed 1 kg/m³.

A.3 REQUIREMENTS FOR SELF-COMPACTING CONCRETE

SCC differs from conventional concrete in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. The various aspects of workability which control its Filling ability, its Passing ability and its Segregation resistance all need to be carefully controlled to ensure that its ability to be placed remains acceptable.

Workability

The level of fluidity of the SCC is governed chiefly by the dosing of the Superplasticizer. However overdosing may lead to the risk of segregation and blockage. Consequently the characteristics of the fresh SCC need to be carefully controlled using preferably two of the different types of test.

Segregation resistance

Due to the high fluidity of SCC, the risk of segregation and blocking is very high. Preventing segregation is therefore an important feature of the control regime. The tendency to segregation can be reduced by the use of a sufficient amount of fines (< 0,125 mm), or using a Viscosity Modifying Admixture (VMA).

Open time

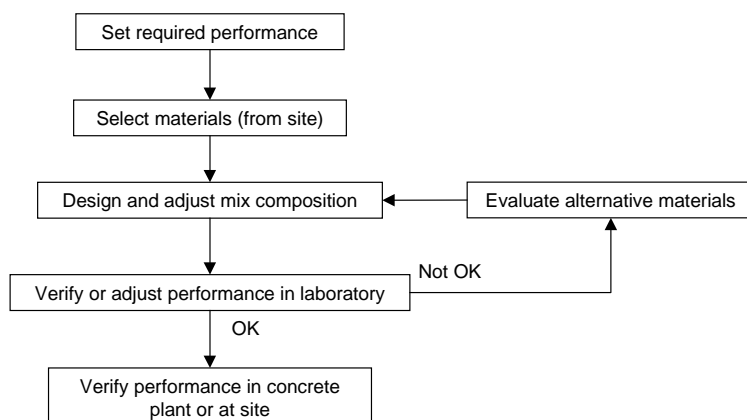
The time during which the SCC maintains its desired rheological properties is very important to obtain good results in the concrete placing. This time can be adjusted by choosing the right type of superplasticizers or the combined use of retarding admixtures. Different admixtures have different effects on open time, and they can be used according to the type of cement and the timing of the transport and placing of the SCC.

A.4 MIX DESIGN

General

Mix design selection and adjustment can be made according to the procedure shown in Figure 1.

Figure 1: Mix design procedure



In designing the mix it is most useful to consider the relative proportions of the key components by *volume* rather than by mass.

In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate:

- the use of additional or different types of filler, (if available);
- modify the proportions of the sand or the coarse aggregate;
- the use of a viscosity modifying agent, if not already included in the mix;
- adjust the dosage of the superplasticizer and/or the viscosity modifying agent;
- the use of alternative types of superplasticizer (and/or viscosity modifying agent) which may be more compatible with local materials;
- different dosage rates of admixture to modify the water content, and hence the water / powder ratio.

Procedure for mix design

An example of a procedure for efficiently designing SCC mixes is shown below. It is based on a method developed by Okamura. It is important to appreciate that this method may result in parameters which differ from those in Chapter 7.2.

The sequence is determined as :

- A) Designation of desired air content (mostly 2 %)
- B) Determination of coarse aggregate volume
- C) Determination of sand content
- D) Design of paste composition
- E) Determination of optimum water:powder ratio and superplasticizer dosage in mortar
- F) Finally the concrete properties are assessed by standard tests.

- A) Definition of desired air content (mostly 2 %)

Air content may generally be set at 2 per cent, or a higher value specified when freeze thaw resistant concrete is to be designed.

- B) Determination of coarse aggregate volume

Coarse aggregate volume is defined by bulk density. Generally coarse aggregate content ($D > 4$ mm) should be between 50 per cent and 60 per cent.

When the volume of coarse aggregate in concrete exceeds a certain limit, the opportunity for collision or contact between coarse aggregate particles increases rapidly and there is an increased risk of blockage when the concrete passes through spaces between steel bars.

The optimum coarse aggregate content depends on the following parameters :

- Maximum aggregate size. The lower the maximum aggregate size, the higher the proportion of coarse aggregate.
- Crushed or rounded aggregates. For rounded aggregates, a higher content can be used than for crushed aggregates.

- C) Determination of sand content

Sand, in the context of this mix composition procedure is defined as all particles larger than 0,125 mm and smaller than 4 mm.

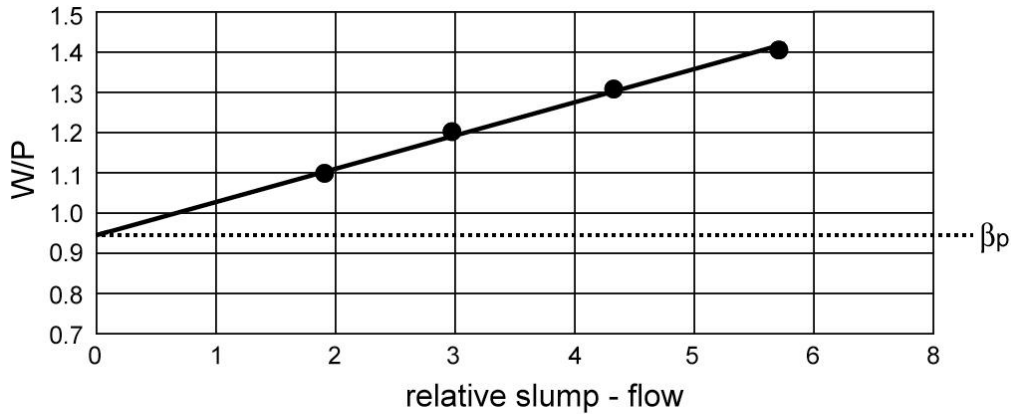
Sand content is defined by bulk density. The optimal volume content of sand in the mortar varies between 40 – 50 % depending on paste properties.

D) Design of paste composition

Initially the water:powder ratio for zero flow (β_p) is determined in the paste, with the chosen proportion of cement and additions. Flow cone tests with water/powder ratios by volume of e.g. 1,1, 1,2, 1,3 and 1,4 are performed with the selected powder composition, see Figure A.1 for typical results. The point of intersection with the y - axis is designated the β_p value.

This β_p value is used mainly for quality control of water demand for new batches of cement and fillers.

Figure A.1 Determination of water powder ratio β_p



E) Determination of optimum volumetric water/powder ratio and superplasticizer dosage in mortar.

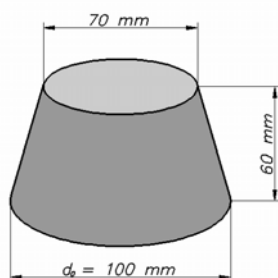
Tests with flow cone and V-Funnel for mortar are performed at varying water/powder ratios in the range of [0,8 – 0,9]. β_p and dosages of superplasticizer. The superplasticizer is used to balance the rheology of the paste. The volume content of sand in the mortar remains the same as determined above.

Target values are slump flow of 24 to 26 cm and V-Funnel time of 7 to 11 seconds.

At target slump flow, where V-funnel time is lower than 7 seconds, then decrease the water/powder ratio. For target slump flow and V-funnel time in excess of 11 seconds, water/powder ratio should be increased.

If these criteria cannot be fulfilled, then the particular combination of materials is inadequate. A trial with a different superplasticizer is the preferred alternative. Second alternative is a new additive, and as a last resort a different cement.

Figure A.2 Flow cone and table to determine the relative slump - flow Γ_p



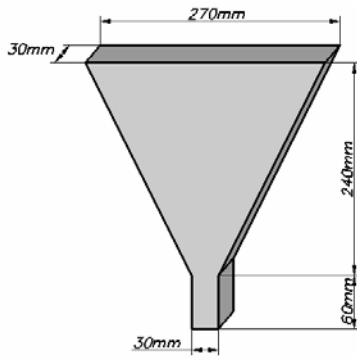
Definition of $\Gamma_{p/m}$:

$$\Gamma_{p/m} = (d/d_0)^2 - 1$$

where:

$$d = \frac{1}{2} (d_1 + d_2)$$

Figure A.3 V-funnel to determine the flow time of the mortar



F) Concrete tests

The concrete composition is now determined and the superplasticizer dosage is finally selected on the basis of concrete tests.

ANNEX B: CHECKLIST

The Checklist has been designed to aid Specifiers, Producers and Contractors in ensuring that all key elements of a SCC application have been considered ahead of the work starting.

Property	Reference	Requirement	Validation
MIX CONSTITUENTS			
Cement		Compliance of EN 197 -1	
		Control of the cement type	
		Recommended cement amount: 350-450 Kg.	
Aggregates		Compliance of EN 12620	
		Control of particles smaller than 0,125 mm	
		Control of moisture content	
		Determination of the sieve curve	
		Compatibility with the space between reinforcement	
Mixing Water		Compliance of prEN 1008	
Admixtures		Compliance of EN 934-2	
		Determination of the types needed	
		Determination of the expected dosage	
Additions		Compliance of prEN 12620, EN 450 or prEN 13263	
		Determination of the sieve curve	
		Definition of the addition to be used	
		Determination of the increase of the water demand	
Pigments		Compliance of 12878	
Raw materials		Definition of all raw materials to be used	
MIX COMPOSITION			
Mix design		Execute the mix design	
		Coarse aggregate < 50%	
		Water powder ratio = 0,8-1,0	
		Total powder content 400-600 Kg /m ³	
		Sand content > 40 % of the mortar (volume)	
		Sand < 50% of paste volume	
		Sand > 50% by weight of total aggregate	
		Free water < 200 l	
		Paste > 40 % of the volume of the mix	
WORKABILITY TESTS			
Slump flow - Abrams		650 – 800 mm	
T _{50cm} slump flow		2 – 5 sec	
J Ring		0 – 10 mm	
V Funnel		8 – 12 sec	
V Funnel- T _{5min}		+ 3 sec.	
L Box		H ₂ / H ₁ = 0,8-1,0	
U Box		H ₂ -H ₁ = 30 mm max	
Fill Box		90 – 100 %	
Screen Stability		0 – 15 %	
Orimet test		0 – 5 sec	
PROPERTIES OF HARDENED CONCRETE			
Mechanical strength		Achieving the expected values after 24h, 7d, 28d	
Shrinkage		As specified	
Mod. of elasticity		Achieving the expected values	
CONFIRMATORY TESTS			
Full scale test		Filling ability	
		Passing ability	
		Segregation resistance	
		Maintenance of the workability > 1 hour	

ANNEX C: TROUBLE-SHOOTING GUIDE

Causes for not fulfilling the specified requirements can be very diverse. In Tables C.1a and C.1b, a list is provided of possible causes for not fulfilling the requirements of the different tests.

If a certain test result is out of range this can have different causes. The possible cause can be found with more certainty by checking the value to other test methods and subjectively checking the workability characteristics. In this way the best possible action for solving a problem can be found. Table C.2 provides a list of possible actions and the effect that usually occurs in concrete. It is obvious that the effect depends upon the size of the action and on the actual workability and composition of the concrete mix. Every action can have both positive and negative effect on the different concrete characteristics.

If the test results between different batches or loads vary considerably, the cause can be the variation of:

- cement characteristics,
- addition characteristics,
- grading of aggregates,
- moisture content of aggregates,
- temperature,
- mixing procedure, time of testing

The use of a viscosity modifying agent (VMA) can suppress some of these variations to a certain extent.

For the understanding of these tables the following definitions apply:

'Yield value' is the force (shear stress) that must be exerted on a material to initiate flow.

'Viscosity' is a measure of the resistance of a material to flow due to internal friction (and is the ratio of applied stress to shear rate)

'Blockage' occurs when a material cannot flow through a specified opening (or orifice) due to interlocking of the aggregate particles

Table C.1a: Fault-finding for low results

			result less than		possible cause
1	slumpflow by Abrams cone	mm	650	a	viscosity too high
				c	yield value too high
2	T _{50cm} slumpflow	sec	2	b	viscosity too low
3	J-ring	mm	10	a	viscosity too high
				c	yield value too high
				d	segregation
				f	blockage
4	V-funnel	sec	8	b	viscosity too low
5	Increase in V-funnel at T _{5minutes}	sec		g	doubtful result
6	L-box (h2/h1)		0,8	a	viscosity too high
				c	yield value too high
				f	blockage
7	U-box (h2-h1)	mm	0	g	false result
8	Fill-box	%	90	a	viscosity too high
				c	yield value too high
9	Screen stability test	%	5	a	viscosity too high
				f	blockage

Table C.1b: Fault-finding for high results

			result more than		possible cause
1	slumpflow by Abrams cone	mm	750	b	viscosity too low
				d	segregation
2	T _{50cm} slumpflow	sec	5	a	viscosity too high
				c	yield value too high
3	J-ring	mm		b	viscosity too low
				d	segregation
4	V-funnel	sec	12	a	viscosity too high
				c	yield value too high
				f	blockage
5	Increase in V-funnel at T _{5minutes}	sec	3	d	segregation
				e	rapid loss in workability
				f	blockage
6	L-box (h ₂ /h ₁)		1	g	false result
7	U-box (h ₂ -h ₁)	mm	30	a	viscosity too high
				c	yield value too high
				f	blockage
8	Fill-box	%	100	g	false result
9	Screen stability test	%	15	d	segregation

Table C.2: Possible corrective actions from identified faults

	possible action	effect on:					
		filling ability	passing ability	segregation resistance	strength	shrinkage	creep
a	viscosity too high						
a1	increase watercontent	+	+	-	-	-	-
a2	increase paste volume	+	+	+	+	-	-
a3	increase superplasticiser	+	+	-	+	0	0
b	viscosity too low						
b1	reduce watercontent	-	-	+	+	+	+
b2	reduce paste volume	-	-	-	-	+	+
b3	reduce superlasticiser	-	-	+	-	0	0
b4	increase viscosity modifying agent	-	-	+	0	0	0
b5	use finer powder	+	+	+	0	-	-
b6	use finer sand	+	+	+	0	-	0
c	yield value too high						
c1	increase superplasticiser	+	+	-	+	0	0
c2	increase paste volume	+	+	+	+	-	-
c3	increase mortar volume	+	+	+	+	-	-
d	segregation						
d1	increase paste volume	+	+	+	+	-	-
d2	increase mortar volume	+	+	+	+	-	-
d3	reduce watercontent	-	-	+	+	+	+
d4	use finer powder	+	+	+	0	-	-
e	rapid loss in workability						
e1	use slower reacting cement type	0	0	-	-	0	0
e2	increase retarder	0	0	-	-	0	0
e3	use different superplasticiser	?	?	?	?	?	?
e4	exchange filler for cement	?	?	?	?	?	?
f	blockage						
f1	reduce maximum aggregate size	+	+	+	-	-	-
f2	increase paste volume	+	+	+	+	-	-
f3	increase mortar volume	+	+	+	+	-	-
g	false result						
g1	check test conditions	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

+	gives usually a better result for concrete
0	has usually no significant result
-	gives usually a worse result for concrete
?	Effect cannot be predicted
n.a.	not applicable

ANNEX D: TEST METHODS

Introduction

It is important to appreciate that none of the test methods for SCC has yet been standardised, and the tests described are not yet perfected or definitive. The methods presented here are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC.

Existing rheological test procedures have not been considered here, though the relationship between the results of these tests and the rheological characteristics of the concrete is likely to figure highly in future work, including standardisation work. Many of the comments made come from the experience of the partners in the EU-funded research project on SCC⁽⁷⁾. A further EU project on test methods is about to start.

In considering these tests, there are a number of points which should be taken into account:

- one principal difficulty in devising such tests is that they have to assess **three** distinct, though related, properties of fresh SCC – its filling ability (flowability), its passing ability (free from blocking at reinforcement), and its resistance to segregation (stability). No single test so far devised can measure all three properties.
- there is no clear relation between test results and performance on site;
- there is little precise data, therefore no clear guidance on compliance limits;
- duplicate tests are advised;
- the test methods and values are stated for maximum aggregate size of up to 20 mm; different test values and/or different equipment dimensions may be appropriate for other aggregate sizes;
- different test values may be appropriate for concrete being placed in vertical and horizontal elements;
- similarly, different test values may be appropriate for different reinforcement densities;
- in performing the tests, concrete should be sampled in accordance with EN 12350-1. It is wise to remix the concrete first with a scoop, unless the procedure indicates otherwise.

Slump flow test (1) and T_{50cm} test (2)

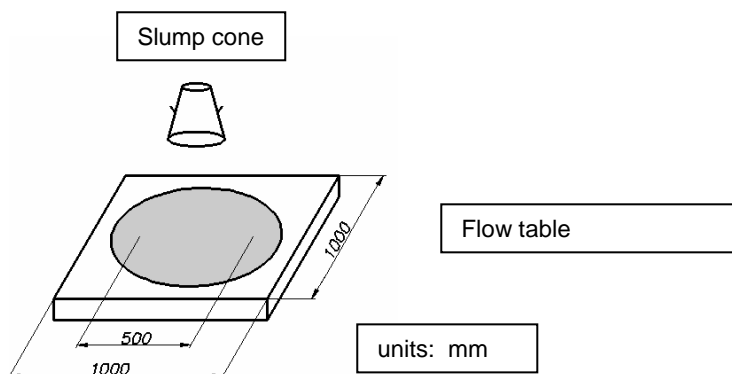
Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan⁽¹⁾ for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of test

This is a simple, rapid test procedure, though two people are needed if the T₅₀ time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

Figure D.1.1



Equipment

The apparatus is shown in figure D.1.1.

- mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm, conforming to EN 12350-2
- base plate of a stiff non absorbing material, at least 700mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel
- scoop
- ruler
- stopwatch (optional)

Procedure

About 6 litre of concrete is needed to perform the test, sampled normally.

Moisten the base plate and inside of slump cone,

Place baseplate on level stable ground and the slumpcone centrally on the base plate and hold down firmly.

Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.

Remove any surplus concrete from around the base of the cone.

Raise the cone vertically and allow the concrete to flow out freely.

Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T_{50} time).

Measure the final diameter of the concrete in two perpendicular directions.

Calculate the average of the two measured diameters. (This is the slumpflow in mm).

Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of *at least* 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50 mm, as with the related flowtable test, might be appropriate.

The T_{50} time is a secondary indication of ~~flow~~ viscosity. A lower time indicates a lower viscosity ~~greater~~ flowability. ~~The Brito EuRam research suggested that a time of 3-7 seconds is acceptable for civil engineering applications, and 2-5 seconds for housing applications.~~

In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. Even if none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

J Ring test (3)

Introduction

The principle of the JRing test may be Japanese, but no references are known. The JRing test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is 300mm, and the height 100 mm.

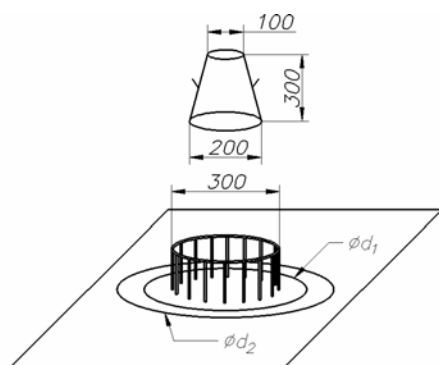
The JRing can be used in conjunction with the Slumpflow, the Orimet test, or eventually even the V-funnel. These combinations test the flowing ability **and** (the contribution of the JRing) the passing ability of the concrete. The Orimet time and/or slumpflow spread are measured as usual to assess flow characteristics. The JRing bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the JRing is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted.

Assessment of test

These combinations of tests are considered to have great potential, though there is no general view on exactly how results should be interpreted. There are a number of options – for instance it may be instructive to compare the slump-flow/JRing spread with the unrestricted slump-flow: to what extent is it reduced?

Like the slump-flow test, these combinations have the disadvantage of being unconfined, and therefore do not reflect the way concrete is placed and moves in practice. The Orimet option has the advantage of being a dynamic test, also reflecting placement in practice, though it suffers from requiring two operators.

Figure D.3.1: the J Ring used in conjunction with the Slump flow



Equipment

- mould, WITHOUT foot pieces, in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm.
- base plate of a stiff non absorbing material, at least 700mm square, marked with a circle showing the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel
- scoop
- ruler
- JRing a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes. In the holes can be screwed threaded sections of reinforcement bar (length 100mm, diameter 10mm, spacing 48 +/- 2mm)

Procedure

About 6 litre of concrete is needed to perform the test, sampled normally.

Moisten the base plate and inside of slump cone,

Place base-plate on level stable ground.

Place the JRing centrally on the base-plate and the and the slump-cone centrally inside it and hold down firmly.

Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.

Remove any surplus concrete from around the base of the cone.

Raise the cone vertically and allow the concrete to flow out freely.

Measure the final diameter of the concrete in two perpendicular directions.

Calculate the average of the two measured diameters. (in mm).

Measure the difference in height between the concrete just inside the bars and that just outside the bars.

Calculate the average of the difference in height at four locations (in mm).

Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

In conjunction with the Orimet. (10)**Equipment**

- Orimet device of a stiff non absorbing material see figure 10.1.
- trowel
- scoop
- stopwatch
- ruler
- JRing a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes. In the holes can be screwed threaded sections of reinforcement bar (length 100mm, diameter 10mm, spacing 48 +/- 2mm); see Figure D.3.1

Procedure

About 8 litre of concrete is needed to perform the test, sampled normally.

Set the Orimet on firm ground.

Moisten the inside surfaces of the casting pipe and the orifice.

Keep the trap door open to allow any surplus water to drain.

Close the trap door and place a bucket underneath.

Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel.

Open the trap door within 10 seconds after filling and allow the concrete to flow out under gravity.

Simultaneously, start the stopwatch and record the time

Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time**). This is taken to be when light is seen from above through the orifice section.

Measure the final diameter of the concrete in two perpendicular directions.

The whole test has to be performed within 5 minutes.

Calculate the average of the two measured diameters. (in mm).

Measure the difference in height between the concrete just inside the bars and that just outside the bars.

Calculate the average of the difference in height at four locations (in mm).

Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

It should be appreciated that although these combinations of tests measure flow *and* passing ability, the results are not independent. The measured flow is certainly affected by the degree to which the concrete movement is blocked by the reinforcing bars. The extent of blocking is much less affected by the flow characteristics, and we can say that clearly, the greater the difference in height, the *less* the passing ability of the concrete. Blocking and/or segregation can also be detected visually, often more reliably than by calculation.

Note: The results of the JRing are influenced by the combination method selected and results obtained with different combinations will not be comparable.

V funnel test (4) and V funnel test at T_{5minutes} (5)

Introduction

The test was developed in Japan and used by Ozawa et al⁽⁵⁾. The equipment consists of a V-shaped funnel, shown in Fig.D.4.1.

The described V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 litre of concrete and the time taken for it to flow through the apparatus measured.

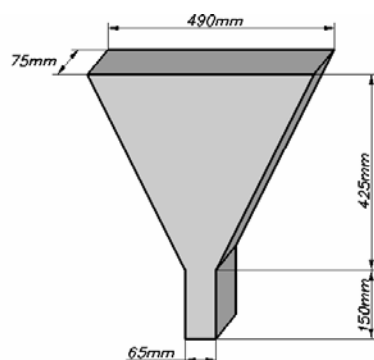
After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Assessment of test

Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction.

While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete is not clear.

Figure D.4.1: V-funnel test equipment (rectangular section)



Equipment

- V-funnel
- bucket (±12 litre)
- trowel
- scoop
- stopwatch

Procedure flow time

About 12 litre of concrete is needed to perform the test, sampled normally.

Set the V-funnel on firm ground.

Moisten the inside surfaces of the funnel.

Keep the trap door open to allow any surplus water to drain.

Close the trap door and place a bucket underneath.

Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel.

Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity.

Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time**). This is taken to be when light is seen from above through the funnel.

The whole test has to be performed within 5 minutes.

Procedure flow time at $T_{5 \text{ minutes}}$

Do NOT clean or moisten the inside surfaces of the funnel again.

Close the trap door and refill the V-funnel immediately after measuring the flow time.

Place a bucket underneath.

Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel.

Open the trap door 5 minutes after the second fill of the funnel and allow the concrete to flow out under gravity.

Simultaneously start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time at $T_{5 \text{ minutes}}$**). This is taken to be when light is seen from above through the funnel.

Interpretation of result

This test measures the ease of flow of the concrete; shorter flow times indicate greater flowability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking.

After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

L box test method (6)

Introduction

This test, based on a Japanese design for underwater concrete, has been described by Petersson ⁽²⁾.

The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus is shown in figure D.6.1.

The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted.

The vertical section is filled with concrete, then the gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H_2/H_1 in the diagram). It indicates the *slope* of the concrete when at rest. This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted.

The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T_{20} and T_{40} times and are an indication for the filling ability.

The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate.

The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

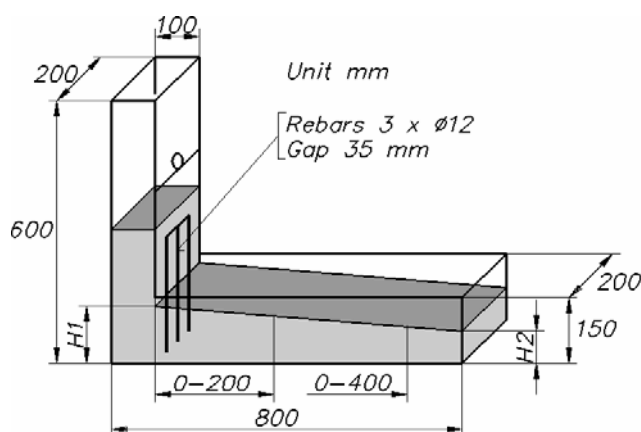
Assessment of test

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section. Unfortunately there is no agreement on materials, dimensions, or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork.

Two operators are required if times are measured, and a degree of operator error is inevitable.

Equipment

- L box of a stiff non absorbing material see figure D.6.1.
- trowel
- scoop
- stopwatch

Figure D.6.1: L-box**Procedure**

About 14 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.

Moisten the inside surfaces of the apparatus, remove any surplus water

Fill the vertical section of the apparatus with the concrete sample.

Leave it to stand for 1 minute.

Lift the sliding gate and allow the concrete to flow out into the horizontal section.

Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks.

When the concrete stops flowing, the distances “H₁” and “H₂” are measured.

Calculate H_2/H_1 , **the blocking ratio**.

The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so $H_2/H_1 = 1$. Therefore the nearer this test value, the ‘blocking ratio’, is to unity, the better the flow of the concrete. The EU research team suggested a minimum acceptable value of 0.8. T_{20} and T_{40} times can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

U box test method (7)**Introduction**

The test was developed by the Technology Research Centre of the Taisei Corporation in Japan ⁽⁴⁾

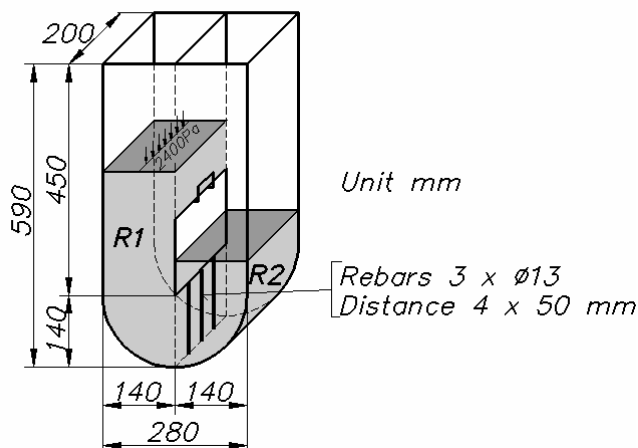
Sometimes the apparatus is called a “box-shaped” test. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Fig.D.7.1

An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacings of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litre of concrete then the gate lifted and concrete flows *upwards* into the other section. The height of the concrete in both sections is measured.

Note: An alternative design of box to this, but built on the same principle is recommended by the Japan Society of Civil Engineers.

Assessment of test

This is a simple test to conduct, but the equipment may be difficult to construct. It provides a good direct assessment of filling ability – this is literally what the concrete has to do – modified by an unmeasured requirement for passing ability. The 35mm gap between the sections of reinforcement may be considered too close. The question remains open of what filling height *less than* 30 cm. is still acceptable.

Figure D.7.1**Equipment**

- U box of a stiff non absorbing material see figure D.7.1.
- trowel
- scoop
- stopwatch

Procedure

About 20 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.

Moisten the inside surfaces of the apparatus, remove any surplus water

Fill the one compartment of the apparatus with the concrete sample.

Leave it to stand for 1 minute.

Lift the sliding gate and allow the concrete to flow out into the other compartment.

After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H_1). Measure also the height in the other compartment (H_2)

Calculate $H_1 - H_2$, **the filling height.**

The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so $H_1 - H_2 = 0$. Therefore the nearer this test value, the 'filling height', is to zero, the better the flow and passing ability of the concrete.

Fill box test method (8)

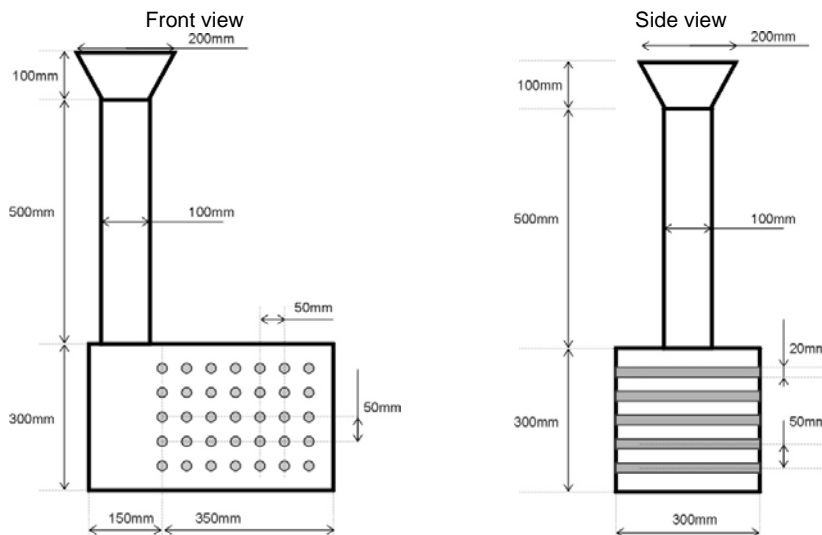
Introduction

This test is also known as the 'Kajima test'. The test is used to measure the filling ability of self-compacting concrete with a maximum aggregate size of 20mm. The apparatus consists of a container (transparent) with a flat and smooth surface. In the container are 35 obstacles made of PVC with a diameter of 20mm and a distance centre to centre of 50mm: see Figure D.8.1. At the top side is put a filling pipe (diameter 100mm height 500mm) with a funnel (height 100mm). The container is filled with concrete through this filling pipe and the difference in height between two sides of the container is a measure for the filling ability.

Assessment of test

This is a test that is difficult to perform on site due to the complex structure of the apparatus and large weight of the concrete. It gives a good impression of the self-compacting characteristics of the concrete. Even a concrete mix with a high filling ability will perform poorly if the passing ability and segregation resistance are poor.

Figure D.8.1



Equipment

- Fill box of a stiff, transparent, non absorbing material
- scoop ca 1,5 to 2 litre
- ruler
- stopwatch

Procedure

About 45 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground.

Moisten the inside surfaces of the apparatus, remove any surplus water

Fill the apparatus with the concrete sample.

Fill the container by adding each 5 seconds one scoop with 1,5 to 2litrer of fresh concrete into the funnel until the concrete has just covered the first top obstacle.

Measure after the concrete has come to rest, the height at the side at which the container is filled on two places and calculate the average (h_1).

Do this also on the opposite side (h_2).

Calculate the average filling percentage:

$$\text{Average filling \%} = \frac{F = \{(h_1 + h_2) / 2 * h_1\}}{h_1} * 100\%$$

The whole test has to be performed within 8 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so Average filling percentage = 100%. Therefore the nearer this test value, the 'filling height', is to 100%, the better the self-compacting characteristics of the concrete.

GTM screen stability test method (9)

Introduction

This test has been developed by the French contractor, GTM, to assess segregation resistance (stability). It consists of taking a sample of 10 litre of concrete, allowing it to stand for a period to allow any internal segregation to occur, then pouring half of it on to a 5mm sieve of 350mm diameter, which stands on a sieve pan on a weigh scale. After two minutes, the mortar which passed *through* the sieve is weighed, and expressed as a percentage of the weight of the original sample *on* the sieve.

Assessment of test

Practising engineers who have used this test say it is a very effective way of assessing the stability of SCC. However, though simple, it is not a rapid test, and requires an accurate weigh-scale, so may not be too suitable for site use. The repeatability of results may be questionable.

Equipment

- 10 litre bucket with lid
- 5 mm sieve 350 mm diameter
- sieve pan
- balance, accuracy 20g minimum capacity 20 kg
- stopwatch

Procedure

About 10 litre of concrete is needed to perform the test, sampled normally.

Allow the concrete in the bucket to stand for 15 minutes covered with a lid to prevent evaporation.

Determine the mass of the empty sieve pan

Inspect the surface of the concrete if there is any bleeding water and note it.

Pour the top 2 litre or approximately 4,8kg \pm 0,2kg only of the concrete sample within the bucket into a pouring container

Determine the mass of the filled pouring container.

Determine the mass of the empty sieve pan.

Pour all the concrete from the pouring container onto the sieve from a height of 500mm in one smooth continuous movement.

Weigh the empty pouring container.

Calculate mass of concrete poured onto sieve, M_a . (i.e. the difference between the weights full and empty).

Allow the mortar fraction of the sample to flow through the sieve into the sieve pan for a period of 2 minutes.

Remove sieve and determine mass of 'filled' sieve pan. Calculate mass of sample passing sieve, M_b , by subtracting the empty sieve pan mass from the filled sieve pan mass.

Calculate the percentage of the sample passing sieve,
the segregation ratio: $(M_b/M_a) \times 100$.

Interpretation of result

Empirical observations suggest that if the percentage of mortar which has passed through the sieve, the segregation ratio, is between 5 and 15% of the weight of the sample, the segregation resistance is considered satisfactory. Below 5% the resistance is excessive, and likely to affect the surface finish (blow holes likely). Above 15%, and particularly above 30%, there is strong likelihood of segregation.

Orimet test (10)

Introduction

The Orimet was developed at the University of Paisley ⁽³⁾ as a method for assessment of highly workable, flowing fresh concrete mixes on construction sites. The equipment is shown in figure 10.1.

The test is based on the principle of an orifice rheometer. The Orimet consists of a vertical casting pipe fitted with a changeable inverted cone-shaped orifice at its lower, discharge, end, with a quick-release trap door to close the orifice. Usually the orifice has an 80 mm internal diameter which is appropriate for assessment of concrete mixes of aggregate size not exceeding 20 mm. Orifices of other sizes, usually from 70 mm to 90 mm in diameter, can be fitted instead.

Operation consists simply of filling the Orimet with concrete then opening the trapdoor and measuring the time taken for light to appear at the bottom of the pipe (when viewed from above).

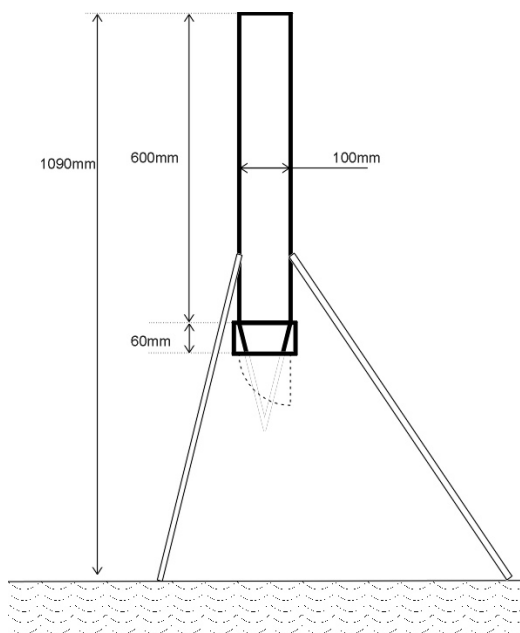
Assessment of test

This test is able to simulate the flow of fresh concrete during actual placing on sites. It is a rapid test, and the equipment is simple and easily maintained. The test has the useful characteristic of being capable of *differentiation* between highly workable, flowing mixes, and might therefore be useful for compliance testing of successive loads on site. The timing procedure, however, may be subject to error, and ideally requires two people.

Equipment

- Orimet device of a stiff non absorbing material see figure D.10.1.
- bucket (±10 litre)
- trowel
- scoop
- stopwatch

Figure D.10.1



Procedure

About 8 litre of concrete is needed to perform the test, sampled normally.

Set the Orimet on firm ground.

Moisten the inside surfaces of the casting pipe and the orifice.

Keep the trap door open to allow any surplus water to drain.

Close the trap door and place a bucket underneath.

Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel.

Open the trap door within 10 seconds after filling and allow the concrete to flow out under gravity.

Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (**the flow time**). This is taken to be when light is seen from above through the orifice section. The whole test has to be performed within 5 minutes.

Interpretation of result

This test measures the ease of flow of the concrete; shorter flow times indicate greater flowability. For SCC a flow time of 5 seconds or less is considered appropriate. The inverted cone shape at the orifice restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking and/or segregation.

ANNEX E: References

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